Possible Orbit Scenarios for an InSAR Formation Flying Microsatellite Mission

Erica Peterson¹,², Robert E. Zee¹, Georgia Fotopoulos²

¹Space Flight Laboratory, University of Toronto
²Department of Civil Engineering, University of Toronto

Presented at the 22nd Annual Conference on Small Satellites
Logan, Utah
12 August 2008
Introduction

- UTIAS/SFL CanX-4 and CanX-5: formation flight in 2009
  - Sub-decimeter baseline knowledge, arc-second attitude knowledge
  - Assume sub-centimeter baseline knowledge (GRACE)
- Application for future mission: multistatic InSAR
  - One transmitter, multiple receivers
  - Enables single-pass interferometry
  - Many applications: DEMs, deformation modeling, small time-scale differential interferometry, super-resolution, moving target detection
- Goals: evaluate scenarios for a future multistatic InSAR formation flight mission, build tools for future constellation analysis and design
Methodology

Scenarios:
- Transmitter options
  • “Large” C-band, X-band
  • Microsatellite X-band
- Orbital configurations
  • Cross-track pendulum
  • Interferometric Cartwheel
  • Varied following distance

Applications:
- Digital elevation modeling

Evaluate:
- Available baselines
- Ground coverage
Transmitters

- 90° inclination, 600km circular orbits (for consistency)
- Parameters of current “large” missions (Radarsat-2, TerraSAR-X)
- Microsatellite limitations (power, mass, size)
  - Assumes deployable antenna

<table>
<thead>
<tr>
<th>Parameters</th>
<th>C-band</th>
<th>X-band</th>
<th>X-micro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength (cm)</td>
<td>5.5</td>
<td>3.1</td>
<td>3.1</td>
</tr>
<tr>
<td>Bandwidth (MHz)</td>
<td>100</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>Transmit power (W)</td>
<td>1650</td>
<td>2200</td>
<td>150</td>
</tr>
</tbody>
</table>
# Orbital Configurations

<table>
<thead>
<tr>
<th>Cross-track pendulum</th>
<th>Interferometric cartwheel</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAAN varies</td>
<td>Arg. of perigee and RAAN evenly spaced through 360°, eccentricity varies</td>
</tr>
<tr>
<td>• Swinging motion in cross-track direction</td>
<td></td>
</tr>
<tr>
<td>• Cross-track baseline determined by RAAN</td>
<td></td>
</tr>
<tr>
<td>• Along-track baseline independently adjustable</td>
<td></td>
</tr>
<tr>
<td>• No vertical baseline</td>
<td></td>
</tr>
<tr>
<td>• Elliptical “wheel” motion, satellites evenly spaced</td>
<td></td>
</tr>
<tr>
<td>• Size of wheel determined by eccentricity</td>
<td></td>
</tr>
<tr>
<td>• Cross- and along-track baselines identical, vary within envelope</td>
<td></td>
</tr>
<tr>
<td>• Vertical baseline varies between zero and half the maximum cross/along track baseline</td>
<td></td>
</tr>
<tr>
<td>• Baselines not independent</td>
<td></td>
</tr>
</tbody>
</table>
Application: Digital Elevation Modeling

- DEM: determine ground target height through triangulation
- Utilizes cross-track component of the baseline
- As baseline increases: DEM elevation error decreases, signal decorrelation error increases

**Critical (maximum) cross-track baseline:**

\[ B = B_{\text{crit}} = \frac{2Bw \lambda R \tan \theta}{c} \]

- \( B_w \) = bandwidth
- \( \theta \) = incidence angle
- \( \lambda \) = wavelength
- \( R \) = range-to-target
- \( c \) = speed of light

**Critical cross-track baseline, 60° inclination angle**

<table>
<thead>
<tr>
<th>Band</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-band</td>
<td>76.2 km</td>
</tr>
<tr>
<td>X-band</td>
<td>12.9 km</td>
</tr>
<tr>
<td>X-micro</td>
<td>6.4 km</td>
</tr>
</tbody>
</table>
Baselines

- **Pendulum**
  - Cross-track varies between near-zero and $B_{crit}$
  - Along-track and vertical are constant
- **Cartwheel**
  - Cross-track and along-track vary between $B_{crit}$ and $\frac{1}{2}B_{crit}$
  - Vertical varies between zero and $\frac{1}{2}B_{crit}$

![Graphs showing cross-track pendulum and interferometric cartwheel baselines with data points and curves indicating baseline variations over time.](image-url)
Operating Areas

- Intersection of
  - Oval of Cassini (constant signal-to-noise contour)
  - Range ellipse (maximum range contour)
- Maximum cross-track baseline for DEM applications
- Operating area:
  - Increases with transmit power
  - Decreases with wavelength (atmospheric attenuation)
  - Decreases with longer following distance (1000km extreme case shown)
- X-band: optimal coverage
Conclusions

- Transmitters:
  - Microsat feasible, but low power reduces operating area
  - C-band: lower atmospheric attenuation reduces operating area
  - X-band: largest operating area
  - Not definite – other transmitters may be considered

- Orbital configurations:
  - Cross-track pendulum:
    - independent cross- and along-track baselines, no vertical baseline
  - Interferometric cartwheel:
    - cross- and along-track baselines identical, vertical maximum one-half
  - Increased following distance:
    - reduces operating area, more severe in C-band, X-micro cases

- Future work: in-depth application investigation (superresolution and object tracking), real-time onboard processing of interferometric data